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Report on a Method of Measuring Small Differences in Longitude

BY

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AND

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Report on a Method of Measuring Small Differences in Longitude

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A METHOD OF MEASURING SMALL DIFFERENCES IN LONGITUDE.

By E. B. H. WADE and P. A. CURRY.

I.—Introduction.

When the preliminary computations of the Geodetic Survey of Egypt were made it was announced that there were large residuals in azimuth, *viz.*, 5″·1 at Helwan base and 7″·0 at Biba base. These azimuths were then most carefully re-observed and the original values were unshaken. Assuming that these residuals are due to local attraction in the prime vertical, it should be possible to confirm them by longitude observations and the method to be described was devised with that object.

At the two places, Helwan and Biba, where the residuals in azimuth occurred, a series of intermediate stations were occupied in an approximately east and west line across the Nile, spaced about four kilometres apart. These points were fixed by careful resection on to fundamental points of the geodetic triangulation, and their geodetic positions determined with an accuracy comparable with that of the geodetic triangulation points. The difference of longitude between one point and the others in the series was then determined by the method to be described in the present paper. It was thought that the difference between these astronomically determined longitudes and those obtained from the geodetic triangulation would then give a check on the local attraction in the prime vertical as deduced from the azimuths and might throw some light on the causes of this local attraction, which it was considered might possibly be due to the influence of the Nile Valley. Three series of observations were made, one at Helwan in November and December 1911, another at Helwan in May and June 1912, and one at Biba in May and June 1913. The first series was unsatisfactory owing to bad weather but showed certain points where the method could be improved. These improvements were introduced into the second series. Before the third series certain instrumental improvements were made details of which will be given later.

The modest scale on which we have operated and certain shortcomings of the method precluded the possibility of determining local attraction with all the accuracy demanded by geodetic science. Of the shortcomings referred to some have been removed and those remaining are, we think, capable of being removed in ways we shall suggest. The object of our paper is to describe and illustrate our method, which is novel and interesting, and *not* to place on record the definitive local attraction at our stations. With regard to such local attraction we must be content with saying that there does not appear to be abnormal local attraction either at Helwan or Biba, such as is indicated by the residuals quoted above.

As regards Biba the negative result is not surprising, as after our return from the field a revision of the computations showed that the alleged residuals in azimuth were explained by an error in computation. At Helwan the case is different and the residual in azimuth is unexplained.

It is proposed to give a description of the apparatus and method used, a complete example of one night's observations at Biba and a table showing the results found at Helwan and Biba, with the probable errors of the differences of longitude found, and suggested improvements in the method.

II.—Method.

The method, omitting details, is as follows. Two observers, say W and C, occupy intervisible stations, say H and D, and each sets his theodolite to the same altitude h. We will suppose H and D are in the same latitude and the longitude of H exceeds that of D by λ. C is equipped with a chronograph and W with a signalling lamp fitted with an occulting shutter. A given star (preferably near the prime vertical) cuts the h-circle of C, who registers the vertical transit on his chronograph. After a time interval λ the same star will cut the h-circle of W, who registers the vertical transit by releasing the occulting shutter of his lamp. The occultation is registered by C on his chronograph. The interval λ is thus recorded on the chronograph.

III.—Equipment.

Theodolites.—Two 8-in. Troughton and Sims micrometer theodolites were used, fitted with 7 horizontal wires at intervals of approximately 190″ apart and two vertical wires. In one theodolite these wires were fixed but in the other they were mounted on a frame which could be moved in altitude by a micrometer screw. Before the Biba observations new object glasses and z.d. eyepieces were obtained, as the definition was not of the best, and this would be a contributing cause of variability of personal equation. The original levels of sensitiveness 2″·0 per division were replaced by new ones of sensitiveness 0″·8 per division.

Acetylene Lamp with Occulting Shutter.—Diaphragms of different sizes were used with the lamp in the Biba series so as to show as nearly as possible the same relative brightness to the observer at the fixed station. In determining the personal equation when the two stations were only 120 metres apart this diaphragm was reduced to a pinhole. The occulting shutter consisted of a guillotine released by a lever actuated by the finger of the observer. The improved form used at Biba had a two-foot drop. By this means the shutter falls at a high speed and occults the lamp very suddenly. An extra 0″·2 was introduced into the personal equation by this method but this is of course eliminated in the final result.

Saegmüller Chronograph.—In the Helwan series the fixed station was at the Observatory and the standard clock was used with the chronograph, but at Biba a half-seconds chronometer was used instead of the clock. The actual time of observation does not enter into the method.

IV.—Corrections.

Several obvious corrections are needed.

Correction for unknown Δh.—The correction to the vertical transit of any star is $\Delta h \frac{dt}{dh}$. The value of $\frac{dt}{dh}$ can be calculated for the known azimuth and latitude, but it saves trouble and is sufficiently accurate to deduce it from the time taken for the star to pass through the known interval between the first and seventh threads of the theodolite.* And if all the stars used lie as they should near the prime vertical it is permissible to use a mean coefficient for all stars, especially if the first approximation to h is close. Further, if there are 8 stars in a programme, four east and four west, Δh can be determined or eliminated.

Correction for Difference of Latitude.—The difference in seconds of time at which the same star cuts the circle of equal altitude at two stations in the same longitude and different latitudes is

$$\frac{1}{15} (\varphi' - \varphi) \cot A \sec \varphi$$

when $\varphi' - \varphi$ is stated in seconds of arc.

Correction for level reading is of the same form as for Δh.

Correction for Micrometer.—The whole group of seven threads is mounted on a frame which is movable in altitude by a micrometer screw and the correction for a known displacement $m - m_0$ is of the same form as for Δh or $b - b_0$. This correction would be unnecessary but for the following consideration. It may well happen that the difference of longitude between H and D is just equal to that required for a star to cross an integral number of thread intervals. If so, C will be busy recording the transit of a star when he should be on the look-out for an occultation. As the differences of latitude and longitude are very approximately known, a programme can be drawn up in advance showing very approximately the expected differences between transits and occultations and C can raise or lower his whole web through the amount calculated to ensure that occultation signals be received almost midway between transits. By raising in some cases and lowering in others it can be arranged that the mean correction for a night is almost independent of the assumed micrometer constant, which nevertheless was determined as closely as possible.

Correction for personal equation is found from a blank determination in the usual way (*see* VI).

V.—Programme.

A feature of the method is that one does not need to identify stars—a great convenience where faint stars are used. W and C meet at H and make by actual observation a programme of all the promising stars which cut their equal altitude circle, noting time and azimuth, and from these they select eight chosen to be alternately east and west stars and as symmetrical as possible as to brightness and azimuth. The programme gives also the most suitable settings of the micrometer for any station. In order that the programme drawn up shall be valid for the case when W and C are no longer at the same station, the following steps are taken. (*a*) The observers adjust their azimuth circles to give approximately true azimuths by a pointing to Polaris. (*b*) W. sends a flash

* See Curry, Survey Department Paper No. 18, page 30.

signal to C and one minute later both observers set their instruments to the altitude of Polaris. The nominally identical altitudes will thus differ by very approximately the difference of latitude. The knowledge that this is the case is not necessary theoretically speaking, but it is is utilized in drawing up the programme of micrometer settings.

Table I is a programme for observations near Biba on May, 1913.

TABLE I.—PROGRAMME. *May 1, 1913.*

C at g_0: W at g_4: Approx. Z.D. 15°.

STARS.	AZIMUTH.	MICROMETER.	WATCH.	REMARKS.
			h. m. s.	
E	32 (1st appearance) 276 00 50 (central)	10·74	9 53 48	mag. 5 W_1 after C_2
W	15 81 00 40	11·51	10 02 38	mag. 4
E	03 279 00 25	10·80	10 17 53	mag. 2½
W	33 89 00 44	11·38	10 31 00	mag. 4
E	09 261 00 07	10·49	10 39 28	mag. 3
W	27 93 00 34	11·31	10 47 38	mag. 4
E	31 265 00 36	10·56	10 54 43	mag. 5
W	24 90 00 45	11·36	11 13 08	mag. 5

The symbols g_0 g_3 denote the stations occupied by observers C and W respectively. Under "Azimuth" are the horizontal circle readings at which the stars are to be

expected; under "Watch," the watch times at which they are due. The entries under "Micrometer" are the settings at which C must set his micrometer (*see* IV). The numbers under "Remarks" are estimated magnitudes of the stars the names of which are of course not known. The remark "W_1 after C_2" means that W's first transit will come after C's second signal and so on.

VI.—Reduction of Observations.

Table II gives the observation sheet for both observers for the date in question.

TABLE II.—OBSERVATIONS. *May 1, 1913.*

C at g_0: W at g_4.

	C's Observations.			W's Observations.		
STAR.	LEVEL.		MICROMETER.	LEVEL.		MICROMETER.
	E	O		E	O	
1 E	10·2	26·1	10r·740	5·0	20·4	20·000
	9·8	25·7		5·3	1·0	
2 W	7·3	23·7	11·510	5·2	20·2	20·000
	6·6	22·8		4·0	20·1	
3 E	8·8	25·0	10·800	1·8	17·8	20·000
	8·8	25·1		5·5	21·2	
4 W	10·2	26·9	11·380	2·0	18·0	20·000
	9·0	25·6		0·5	16·2	
5 E	12·0	28·7	10·490	7·0	23·2	20·000
	13·1	29·8		6·7	23·0	
6 W	10·5	27·1	11·310	6·0	22·0	20·000
	9·0	25·8		4·0	20·0	
7 E	11·8	28·6	10·560	4·7	21·0	20·000
	10·8	27·5		11·5	28·0	
8 W	10·0	26·9	11·360	7·0	24·0	20·000
	10·2	27·2		5·8	22·3	

TABLE III.

April 1, 1913.

Observations for d λ C at g_0: W at g_4

$\Phi_4 = 28°\ 57'\ 34''$ N $\Phi_0 = 28°\ 55'\ 25''$ N $\Phi_4 - \Phi_0 = 2'\ 9''$

STAR.	1 (E)		2 (W)		3 (E)		4 (W)	
Observer.	C	W	C	W	C	W	C	W
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
Mean of 7 threads	12 38 14·70	12 38 39·13	12 47 43·93	12 47 68·44	13 02 47·56	13 02 72·06	13 16 26·06	13 16 50·56
$K(m-m_0)q =$	+2·95	0·00	+5·82	0·00	+2·29	0·00	+4·28	0·00
$n(b-b_0)q' =$	+0·01	+0·10	−0·20	−0·05	+0·08	+0·10	−0·01	−0·25
$(\varphi_4-\varphi_0)f =$	0·00	−1·14	0·00	+1·46	0·00	−1·59	0·00	+0·08
Sum...	12 38 17·66	12 38 38·00	12 47 49·55	12 47 69·85	13 02 49·93	13 02 70·57	13 16 30·33	13 16 50·39
C—W	−20s·34		20s·30		−20s·64		−20s·06	

STAR.	5 (E)		6 (W)		7 (E)		8 (W)	
Observer.	C	W	C	W	C	W	C	W
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
Mean of 7 threads...	13 24 09·16	13 24 33·99	13 33 13·33	13 33 37·44	13 39 40·37	13 39 65·06	13 57 42·53	13 57 66·66
$K(m-m_0)q =$	+5·83	0·00	+3·51	0·00	4·98	0·00	4·07	0·00
$n(b-b_0)q =$	−0·18	−0·12	0·00	−0·01	−0·10	−0·20	+0·03	+0·10
$(\varphi_4-\varphi_0)f =$	0·00	+1·50	0·00	−0·57	0·00	+0·74	0·00	−0·09
Sum...	13 24 14·81	13 24 35·37	13 33 16·84	13 33 36·86	13 39 45·25	13 39 65·60	13 57 46·63	13 57 66·67
C—W	−20s·56		−20s·02		−20s·35		−20s·04	

Table III gives the reduction of these observations for the date in question.

φ_0 and φ_4 are the latitudes of the stations. The entries against "mean" are the chronograph times, those under C being C's transits, those under W signals from W representing W's transits. The corrections in the next three lines are due to micrometer, level, and difference of latitude. The entries against C—W are the crude differences of longitude. The east stars and the west stars are now formed into separate groups, and the mean of the east stars gives C—W= —10^s·10 and that of the west stars gives C—W=—7^s·94. This difference is due to the fact that the instruments of C and W are not at exactly equal altitudes and the half difference is the systematic error on that account. On applying it with sign — for east and + for west stars we get the figures in Table IV.

TABLE IV.

C at g_0: W at g_4. C — W

May 1, 1913.

$C-W \pm \frac{e-w}{2}\begin{cases} w+ \\ e- \end{cases}$

	East Stars. (e)	West Stars. (w)	
	s		s
1	—20·34		—20·16
2		—20·03	0·48
3	—20·64		0·46
4		—20·06	0·24
5	—20·56		0·38
6		—20·02	0·20
7	—20·35		0·17
8		—20·04	0·22
	—20·47	—20·10	

mean $\frac{e-w}{2}$ = ^{s} —0·18

λ = — 20^s·29 ± 0^s·04

(uncorrected for personal equation).

The quantity —20^s·29 is the concluded difference of the longitude and is affected by personal equation. The personal equation is obtained by a blank observation performed in the way just described for station g_0 and g_4, except that W moves up to g_0 or to a point at a very small known distance away from g_0. The value of λ for W's station should then correspond exactly with this small know distance and any excess is regarded as "personal equation."

VII.—Results.

By the method described we have made, in all, three series af observations, one at Helwan in November and December 1911, one in May and June 1912, and one at Biba in May and June 1913. As it is not the object of this report to give the definite longitude of any station but to describe our method and illustrate its accuracy, and as the Biba series is far more suited for that purpose than either of the Helwan series,we shall deal in a very summary way with these earlier series.

The first series was unsatisfactory for the following reasons: (*a*) the probable error of certain stations was unduly large ; (*b*) the weather was unfavourable on some of the nights; (*c*) far too little care was taken to ensure that the signals from W to C in the blank observations were similar to those from W to C at remote stations and there is no doubt the former were much too bright. The second series was made in excellent weather, and great care was taken to ensure comparability of signals. Only the stations g_2 and g_6 were occupied, but they were each occupied on four nights each with the following result:—

Difference of longitude of g_2 g_6

	s		
astronomical	33·98	computed from geodetic	
	33·81	triangulation	
	34·13		
	33·89		
	s	*s*	
	33·95	± 0·05	34·12

The personal equation in the second series was much lower than in the first, which is presumably the consequence of the reduction of brightness of the signals. In support of this it is noteworthy that if we employ in the reduction of the first series the personal equation furnished by the second, we get for the difference of longitude of g_2—g_6 the value $33^s{\cdot}99$. However, we are not really concerned to discuss observations which are obviously unsatisfactory and will pass on to the Biba series.

In the interval between the Helwan and Biba series a number of improvements were introduced in the light of experience : (*a*) it was decided to work at an altitude of 75° instead of 30° ; (*b*) improved optical parts were introduced into the theodolite because personal equation is thought to be much more stable when there is first rate definition ; (*c*) sensitive levels giving $0''{\cdot}8$ per division were fitted ; (*d*) a greatly improved guillotine with a two-foot drop was used for occulting the lamp ; (*e*) in the determination of personal equation, W and C, instead of being in the same longitude and near together, were separated by 120 metres and a mere pinhole was used as a lamp diaphragm. Thus it is thought that the personal equation determination must have presented a very close similarity to an actual observation, at any rate as close as the occultation method admits of (*see* VIII).

TABLE V.

Station.	Geodetic Positions of Stations.					
	Latitude N.			Longitude E.		
	°	′	″	°	′	″
g_0	28	55	25·35	31	00	31·19
g_1	Not occupied.					
g_2	28	55	26·48	31	00	28·46
g_3	28	56	20·35	30	58	23·59
g_4	28	57	33·84	30	55	33·96
g_5	28	59	04·36	30	52	13·16
g_6	29	00	22·52	30	49	01·21

As a result, partly of experience gained, partly of the improvements introduced, very satisfactory results were obtained. The method of observation and calculation being as before, it only remains to give the results in Table VI.

TABLE VI.

STATION.	DATE.	LONGITUDE FROM G_0 IN TIME.			
		Astronomical including personal equation.	Geodetic.	Astronomical free from personal equation.	G–A
		s			
g_2	14/5/13	—0·82±0·02			
	29/4/13	—0·84±0·06			
		—0·83	*s* —0·18	*s* —0·18	*s* —0·00
		s			
g_3	13/5/13	—9·02±0·03			
	30/4/13	—9·16±0·04			
		—9·09	—8·51	—8·44	—0·07
		s			
g_4	12/5/13	—20·23±0·01			
	1/5/13	—20·29±0·03			
		20·26	—19·81	—19·61	—0·20
		s			
g_5	9/5/13	—33·72±0·04			
	5/5/13	—33·58±0·03			
		—33·65	—33·20	—33·00	—0·01
		s			
g_6	8/5/15	—46·52±0·05			
	7/5/13	—46·60±0·03			
		—46·56	—46·00	—45·91	—0·09

VIII.—Suggested Improvements.

Results such as these are good enough to demonstrate the presence of an abnormally large deviation of the plumb line if it really exists, but they are not accurate enough to rank as definitive geodetic data. It remains to inquire how

the method can be brought up to geodetic standard. The most obvious defect in the method is the use of flash signals. The use of such in our case was justified by the following considerations : we urgently wished for some check on the azimuth data : the use of the galvanic telegraph was out of the question : wireless telegraphy in 1912 had not attained anything like the position which it has to-day nor were either of us then familiar with the art. To-day the use of lamp signals would be inexcusable. The obvious improvement would be for W to depress a light Morse key instead of the trigger of the comparatively clumsy occulting apparatus. This would determine the emission of a wireless signal, preferably from a continuous wave thermionic set. C would wear a headgear telephone receiver connected to the usual continuous wave reception gear. With the dispositions described in the present paper he would *hear* a signal midway between the transits over his threads. It would seem easy to arrange that the signals from a remote station were exactly similar to those from the personal equation station.

Instead of 8-inch theodolites a pair of Zenith telescopes, as used in most geodetic surveys for Talcott latitude, could very appropriately be substituted.

The plan adopted in the present paper of occupying a chain of six stations, in the hope of tracing the development of local attraction, is far too ambitious. If instead of two nights at each of the six stations we had taken six nights at each of the two terminals, we should, with the same or even less effort, have obtained a decidedly more accurate result. But for the purpose of the present paper we do not regret the course adopted, as it illustrates the possibilities of the method better than the course suggested. It is not with every longitude apparatus that one could move one's camp and observe at a new station each night.

VIII.—Conclusions.

Even when all these precautions have been taken, we must still remain of opinion that for intervisible stations and in latitudes north of 20° longitudes can never be but the roughest of checks on azimuth observations, assuming of course that the programmes are comparable as to number of observing nights and observations per night. It is when the conditions as to intervisibility and latitude are not fulfilled that the longitudes become so useful. When the African Survey enters, as it must, equatorial latitudes, it is thought that some such method as we have described will become absolutely indispensable.

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